Radiation Science with High-Energy Electrons

Insoo Jun

Europa Project Radiation Science Focus Group

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Jet Propulsion Laboratory, California Institute of Technology

Introduction

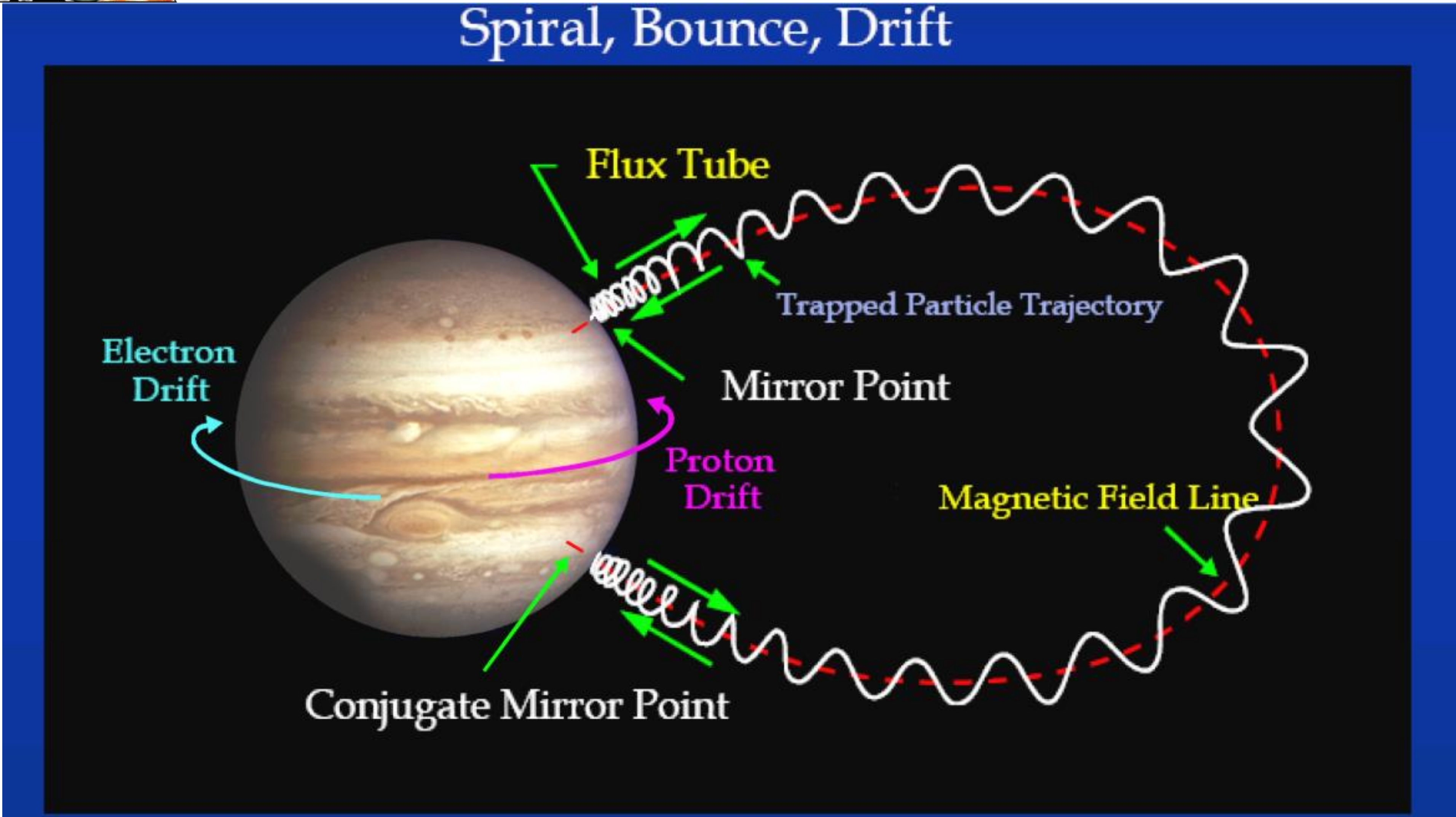
- See previous presentations on the radiation environment and radiation science:
  - "*Radiation Monitoring System Science*" by Europa Radiation Science Working Group, June 2016.
  - "*High-Energy Electron Detection with NASA's Planned Europa Clipper Mission*" by Pich and Jun, May 2017.
  - Two previous talks in this Rad FG presentation series, respectively, by Goldsten and Rymer.
    - RadMon design
    - Hot (~100 keV) Plasma

- The focus of this talk is to discuss on:
  - why 25 MeV?
  - what science we can achieve if we have high-energy (tens of MeV) electron measurement (i.e., by RadMon).

Topics

- (Simplified) Particle motion in the Jovian magnetosphere
- Baseline RadMon design
- Radiation science
- Surface modification
  - Space Weathering
- Dose-depth curve for the ECM mission

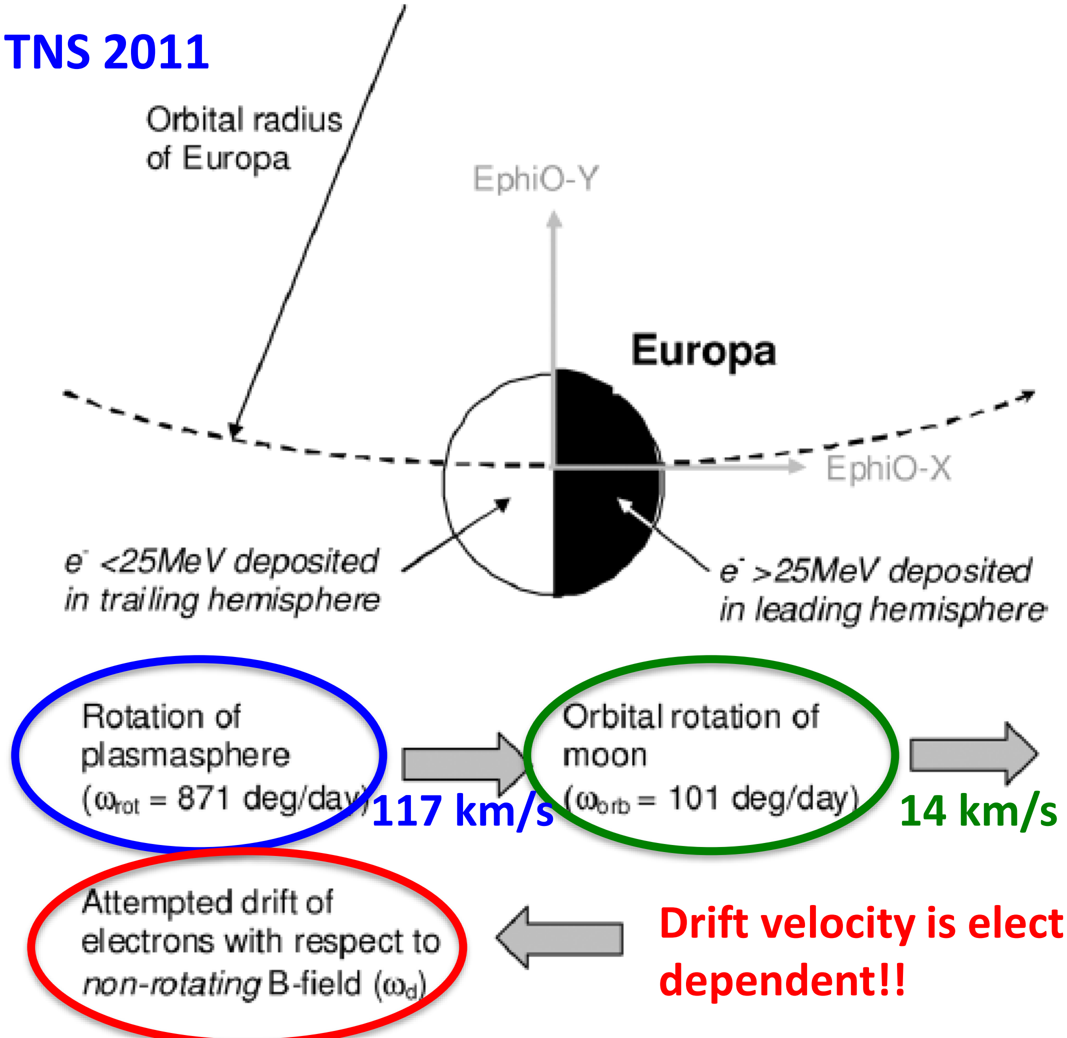
Trapped Particle Motion at Jupiter (1)



- If the magnetosphere of Jupiter is rigidly co-rotating, plasma flow speed at Europa’s orbit (9.5 Rj) is about 117 km/s.
- Europa travels about 14 km/s in its orbit, so that charged particles are overtaking the satellite at all times.

Trapped Particle Motion at Jupiter (2)

Truscott et al., TNS 2011



Drift velocity is electron energy dependent!!

Fig. 1. Diagram showing EPhiO coordinate system and relative motions of plasmasphere and moon, and electron drift.

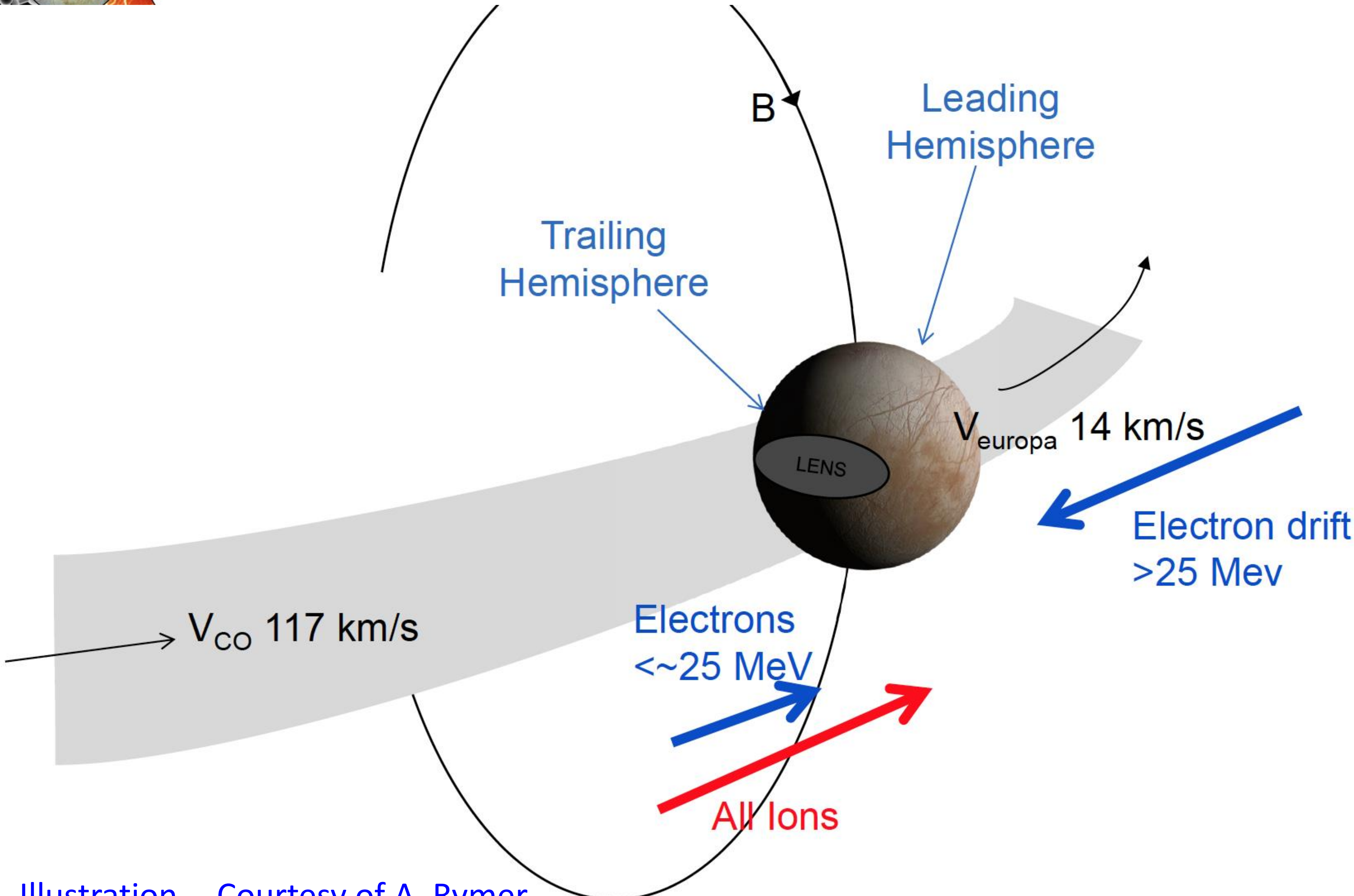


Illustration -- Courtesy of A. Rymer

Ion Motion

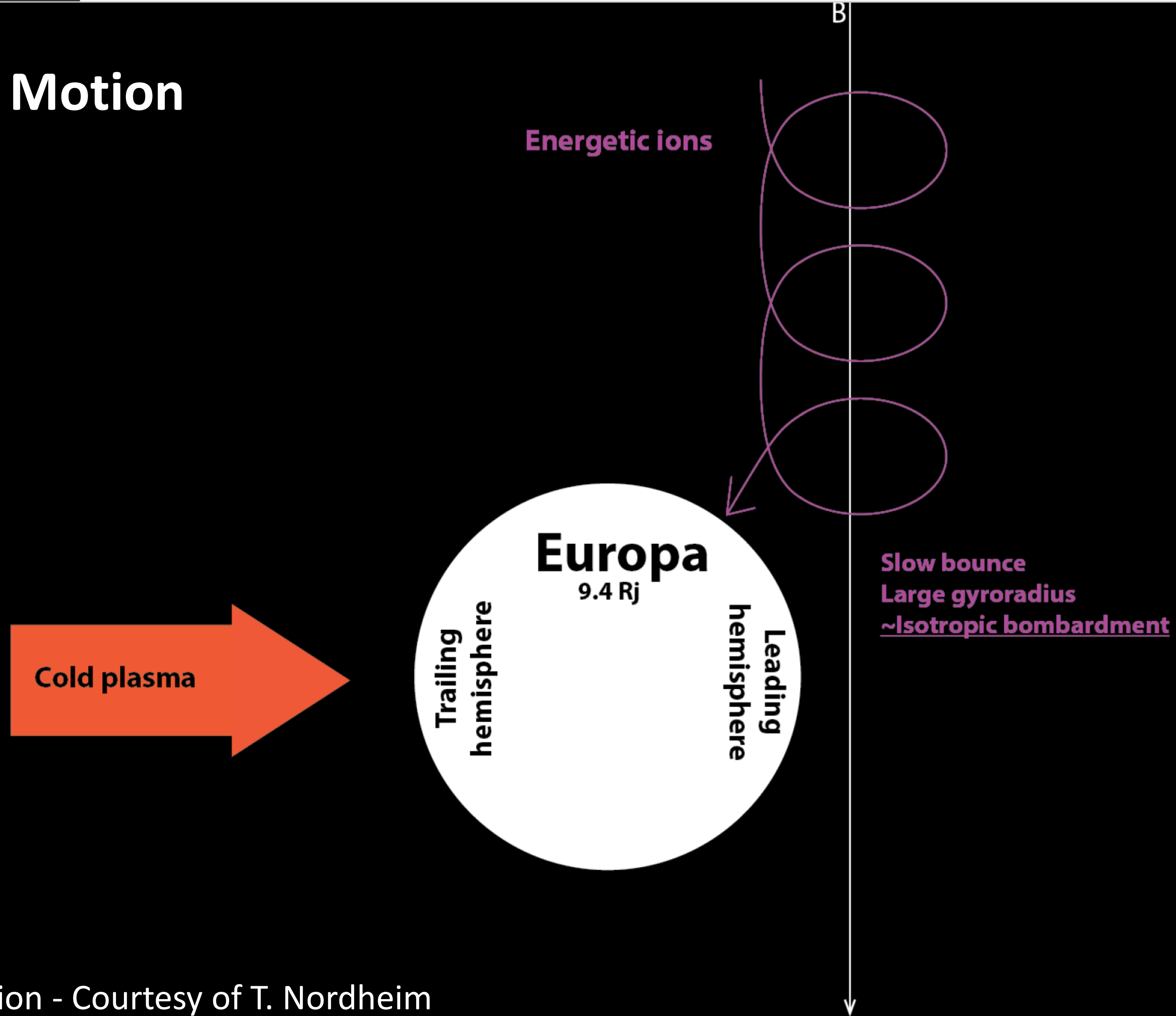
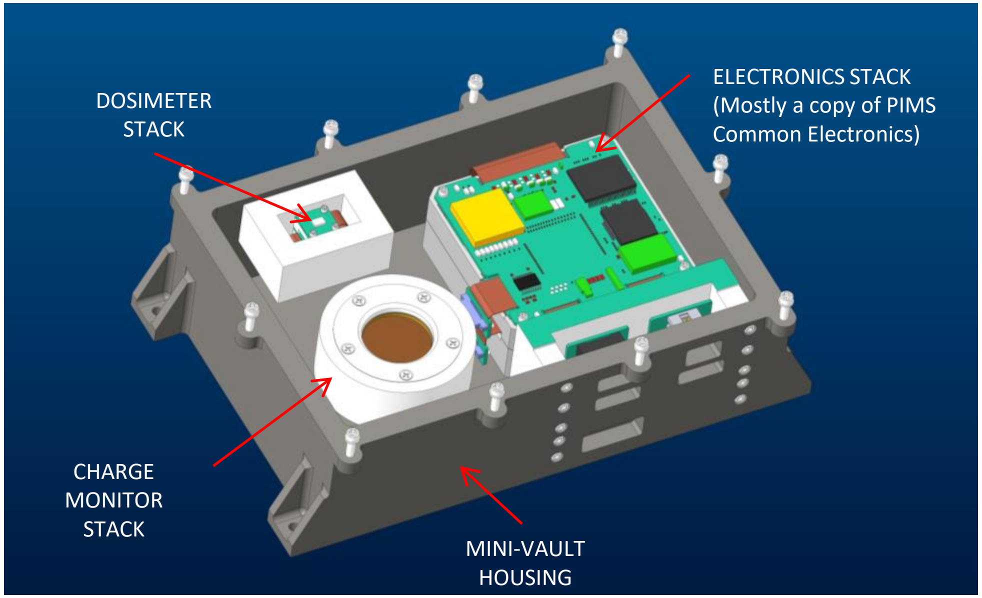
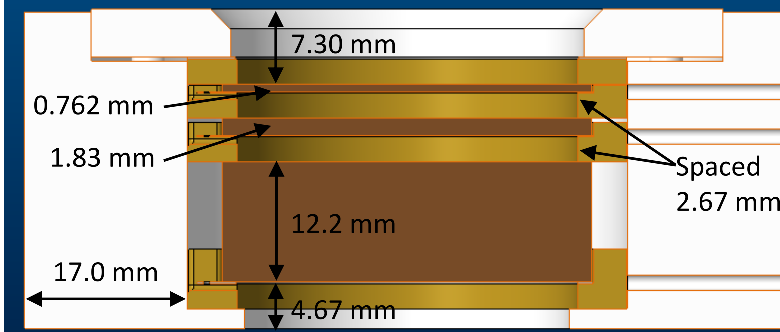


Illustration - Courtesy of T. Nordheim

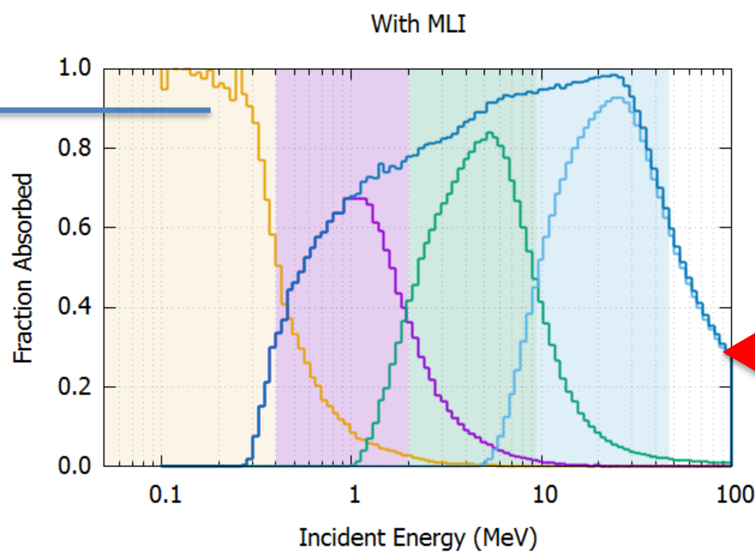
RadMon: Charge Monitor





3 plates baseline

With additional thin layer



Radiation Science

- Measurement of >25 MeV electrons near Europa will be the first of kind:
  - Will provide in-situ measurement to validate the electron energy cutoff between trailing and leading

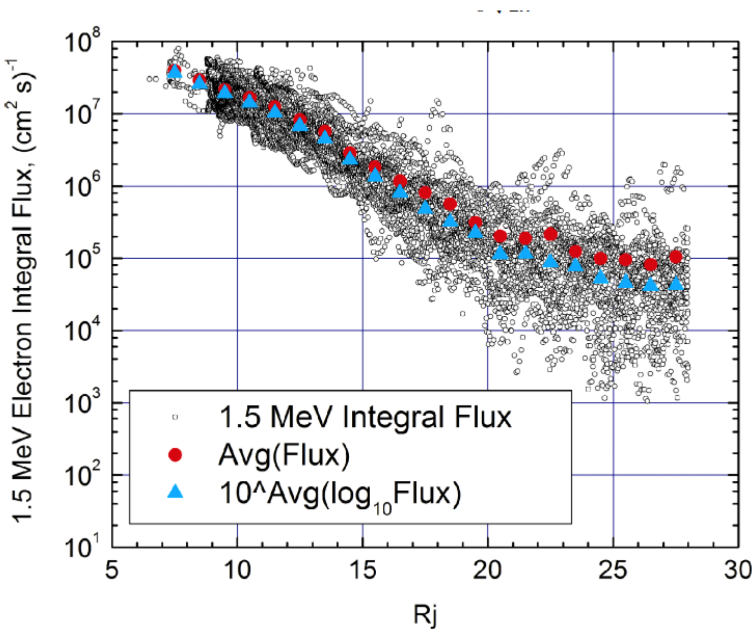
- High-energy electron measurement will enhance our understanding on:
  - Long term variation of high energy trapped electron environment.
  - The physics of how these electrons are energized. This has implications for the source energy spectrum of synchrotron (radio) radiation (de Pater and Dunn 2003). Jupiter is the most powerful synchrotron emitter in the solar system.

- Direct measurements of these penetrating electrons would be useful to plan future missions. MeV electrons are important for updating Jovian radiation models (e.g., GIRE-series models).

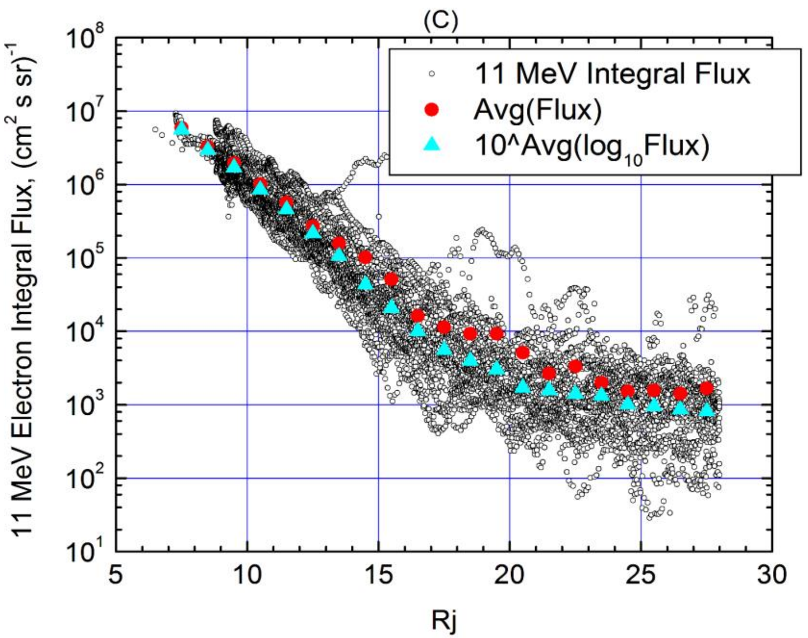
- Landing site selection:
  - The bombardment map from energetic electrons will also inform site selection for a Europa lander. For example, the dose and precipitation maps can inform final site selection.

Long-term variation

Variations in Energetic Particle Detector Fluxes with distance from Jupiter showing "average" and "storm" variations



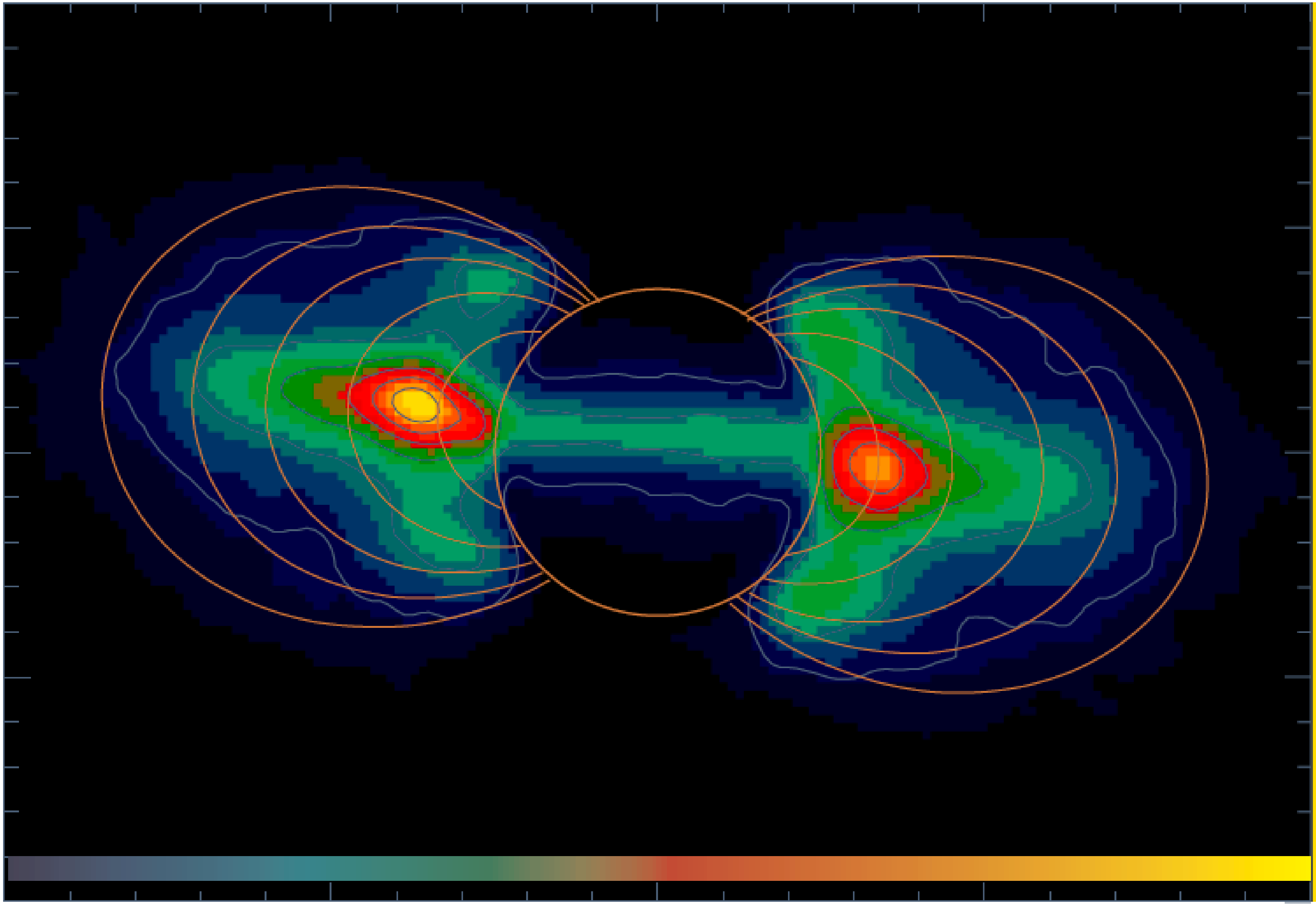
Galileo EPD 1.5 MeV particle fluxes vs radial distance



Galileo EPD 11 MeV particle fluxes vs radial distance

Jun et al., Icarus, 2005

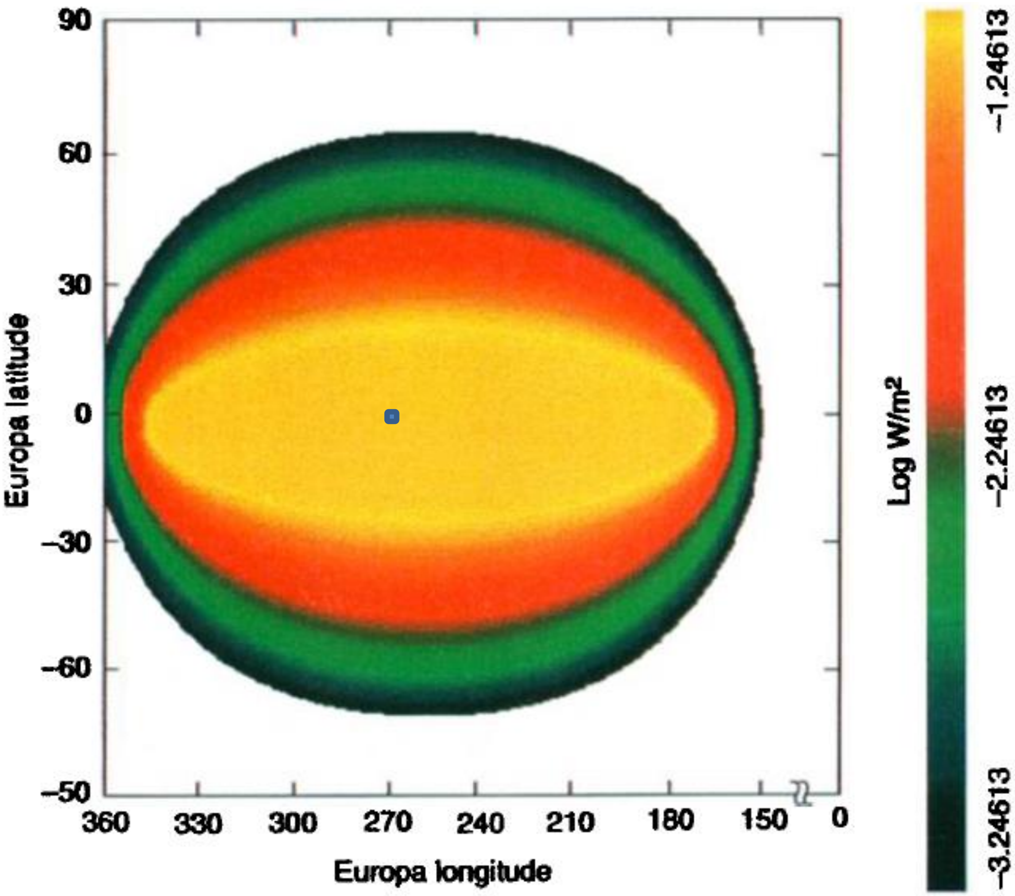
Synchrotron emission at Jupiter (21 cm) from the work of Bolton et al. 2001



Surface Modifications

- The goal of studying the patterns and effects of external agents (photons, charged particles, dust, etc.) is to determine whether surface features have an internal or external cause.
  - Cold plasma, if it reaches the moon's surface, can create a bull's-eye pattern on the trailing hemisphere (it should fall off from the trailing apex as a function of both longitude and latitude)
  - Energetic particles will be less influenced by the local electromagnetic fields (e.g., they are unaffected by surface charging) and precipitate directly into the surface ice in a pattern that depends on their species and energy (see, for instance, Cassidy et al., PSS, 2013)
  - Precipitating electrons can cause physical and chemical changes in the ice and non-ice materials on Europa's surface.
  - Carlson et al. (2009 Europa book chapter) provides a comprehensive summary of many processes that are expected.
  - The implications for weathering of non-ice materials on Europa are not fully developed.

Europa: Distribution of Dose Rate on Surface

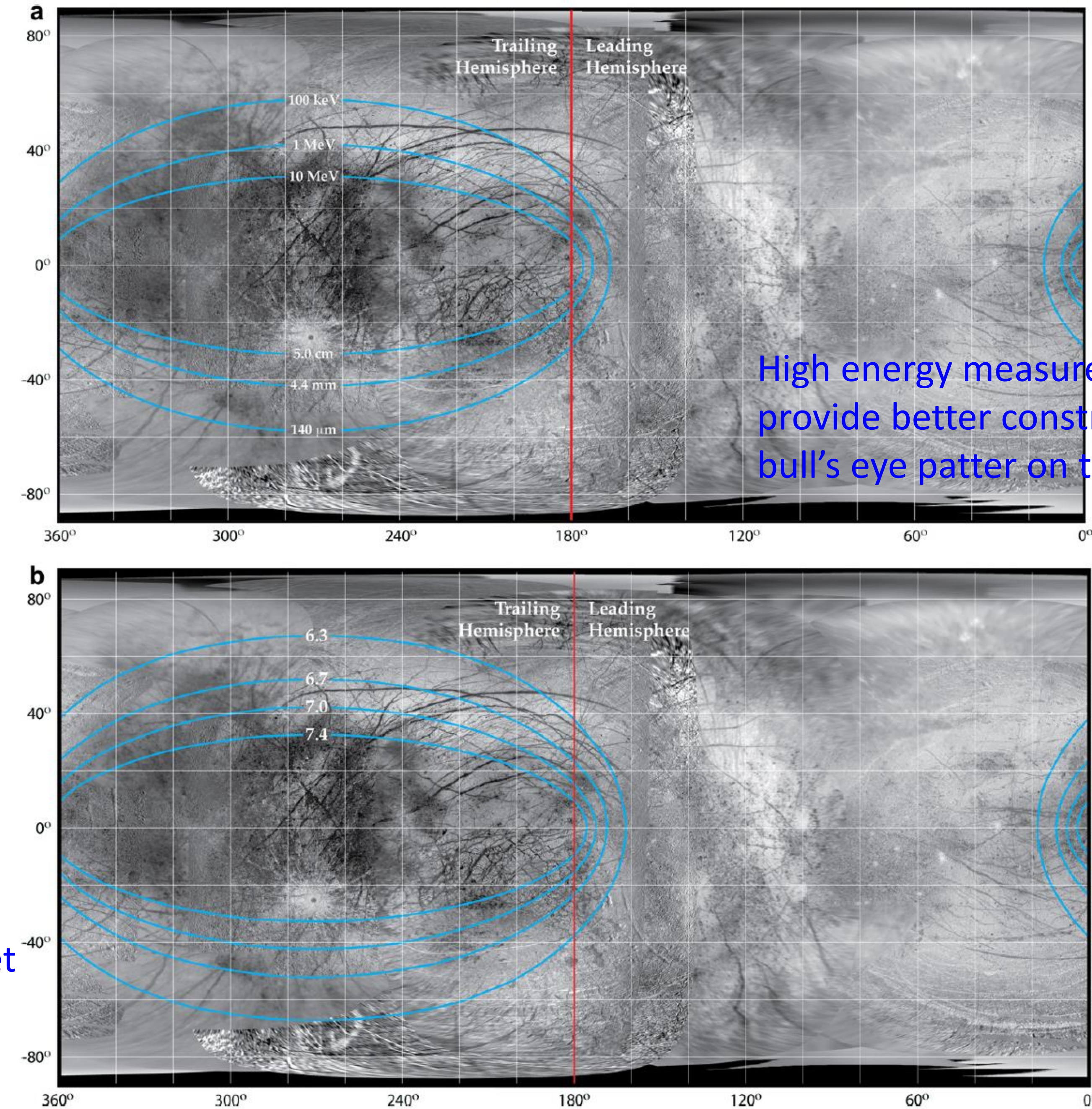


- Paranicas et al. 2001

Dot at lat/lon = 0°/270° is center of trailing side, extending from 180° to 360° longitude.

Electrons with energies up to ~ 25 MeV hit the trailing side of Europa.

Electrons > ~25 MeV hit the leading side. (Less dose, but hard to shield.)

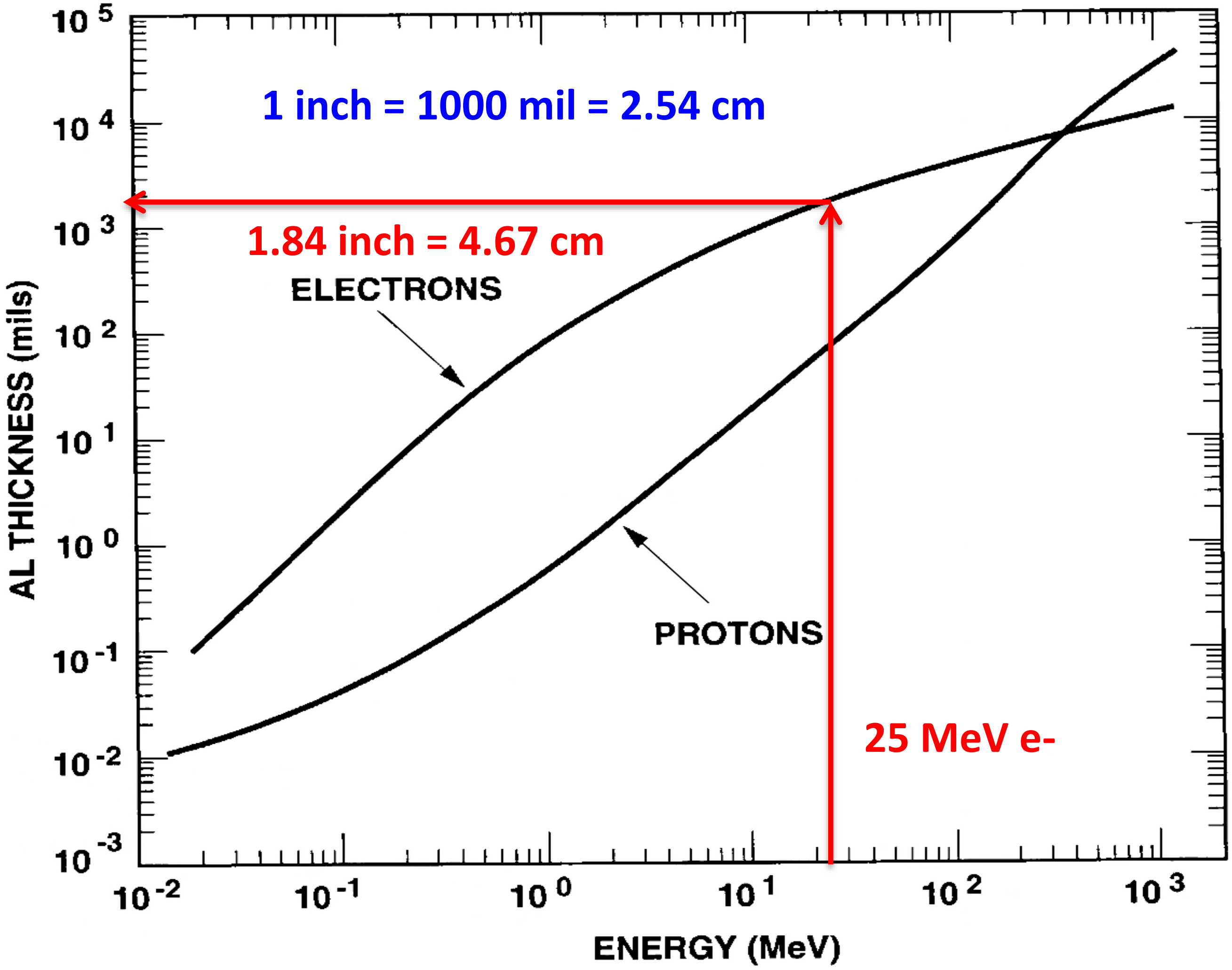


High energy measurements can provide better constraints on the bull's eye patter on the surface

Patterson et al, Icarus, 2012

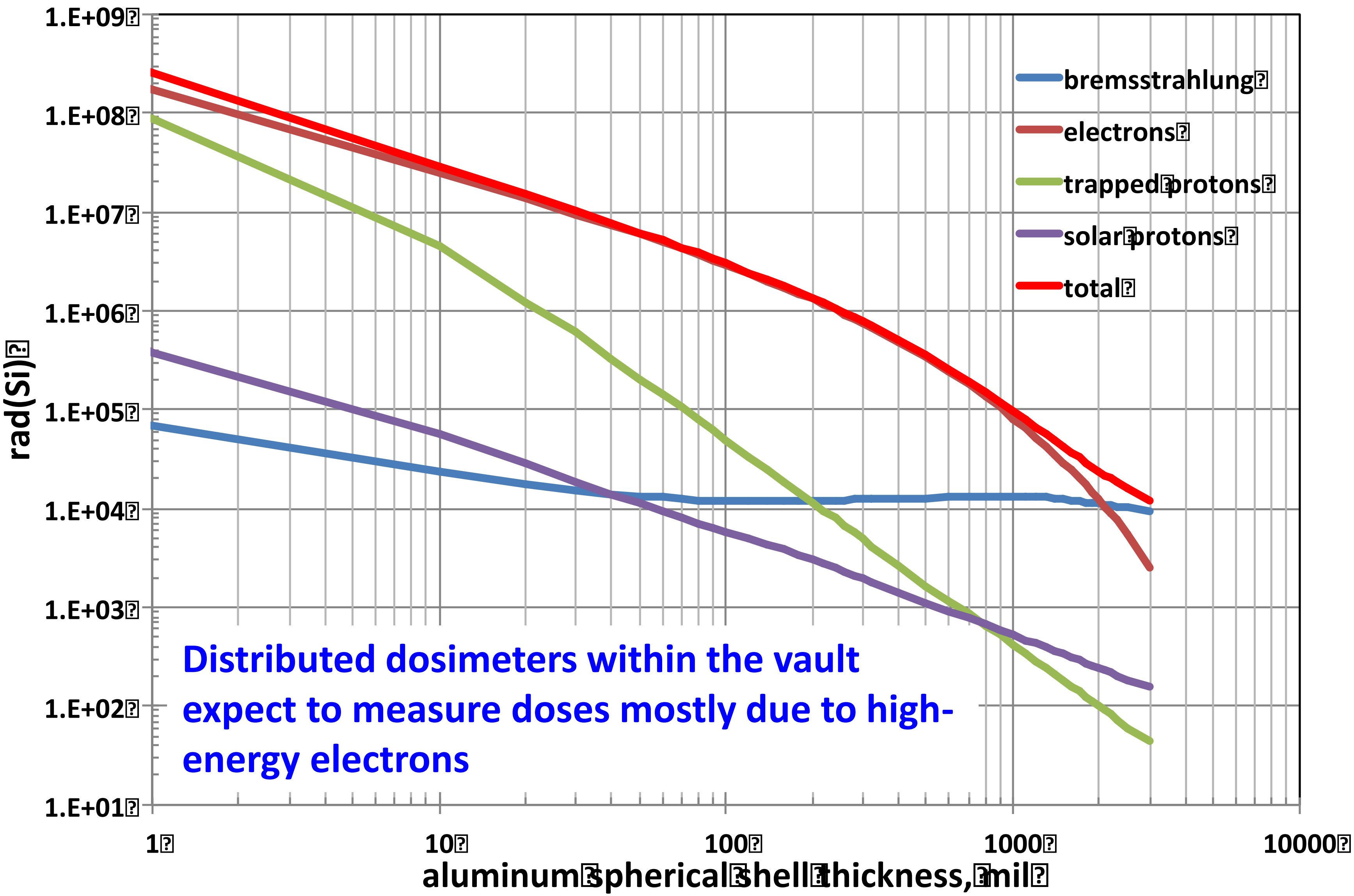
Fig. 2. Contour plots of electron bombardment of Europa for a λ_m of 45° overlain on a simple cylindrical mosaic of the surface indicating (a) energies and penetration depths for 100 keV, 1 MeV and 10 MeV electrons and (b) the integrate flux of electrons into the surface in the energy range from 10 keV to 25 MeV expressed in units of $\log_{10}$ MeV cm^{-2} s^{-1}. A λ_m of 45° was used because it encompasses 96% of the particles in a trapping pitch angle distribution at a given energy. Contours of constant energy represent contours of constant d_p.

CHARGED PARTICLE INTERACTIONS
PROTON/ELECTRON ENERGY vs PENETRATION DEPTH FOR AL



The current vault wall thickness is 1 cm or ~ 400 mil of aluminum

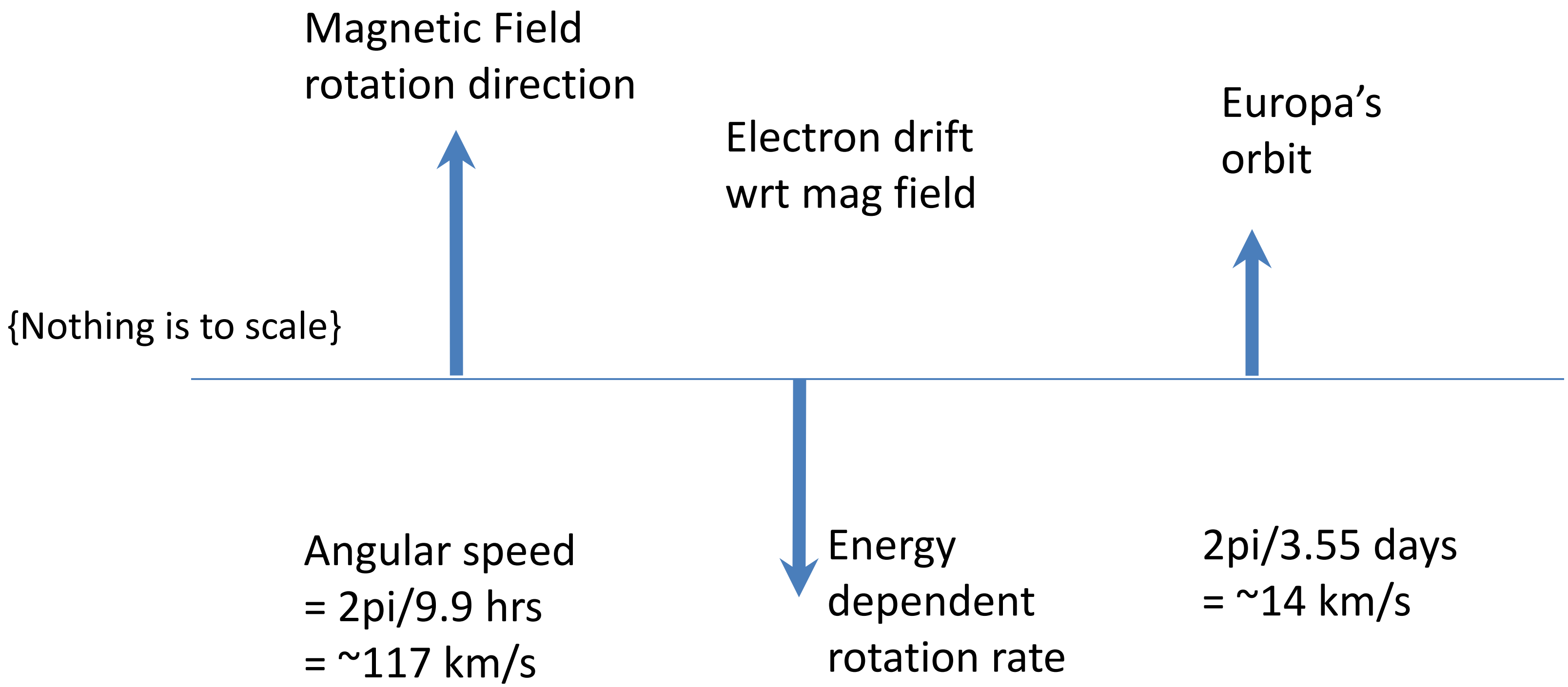
Dose-Depth Curve



Distributed dosimeters within the vault expect to measure doses mostly due to high-energy electrons

BACKUP

Exposure depends on Rotation Rates: Electrons

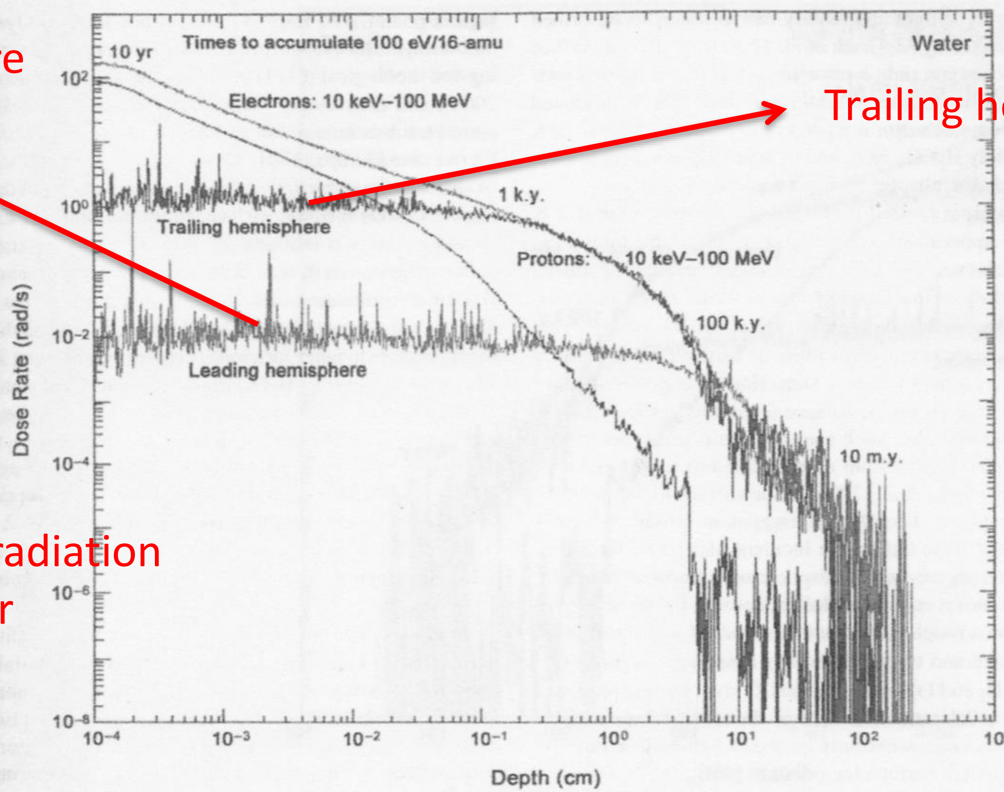


- Sum of field and electron-drift speeds equals Europa speed at about 25 MeV.

Electron dose rate bounds

Leading hemisphere

Trailing hemisphere

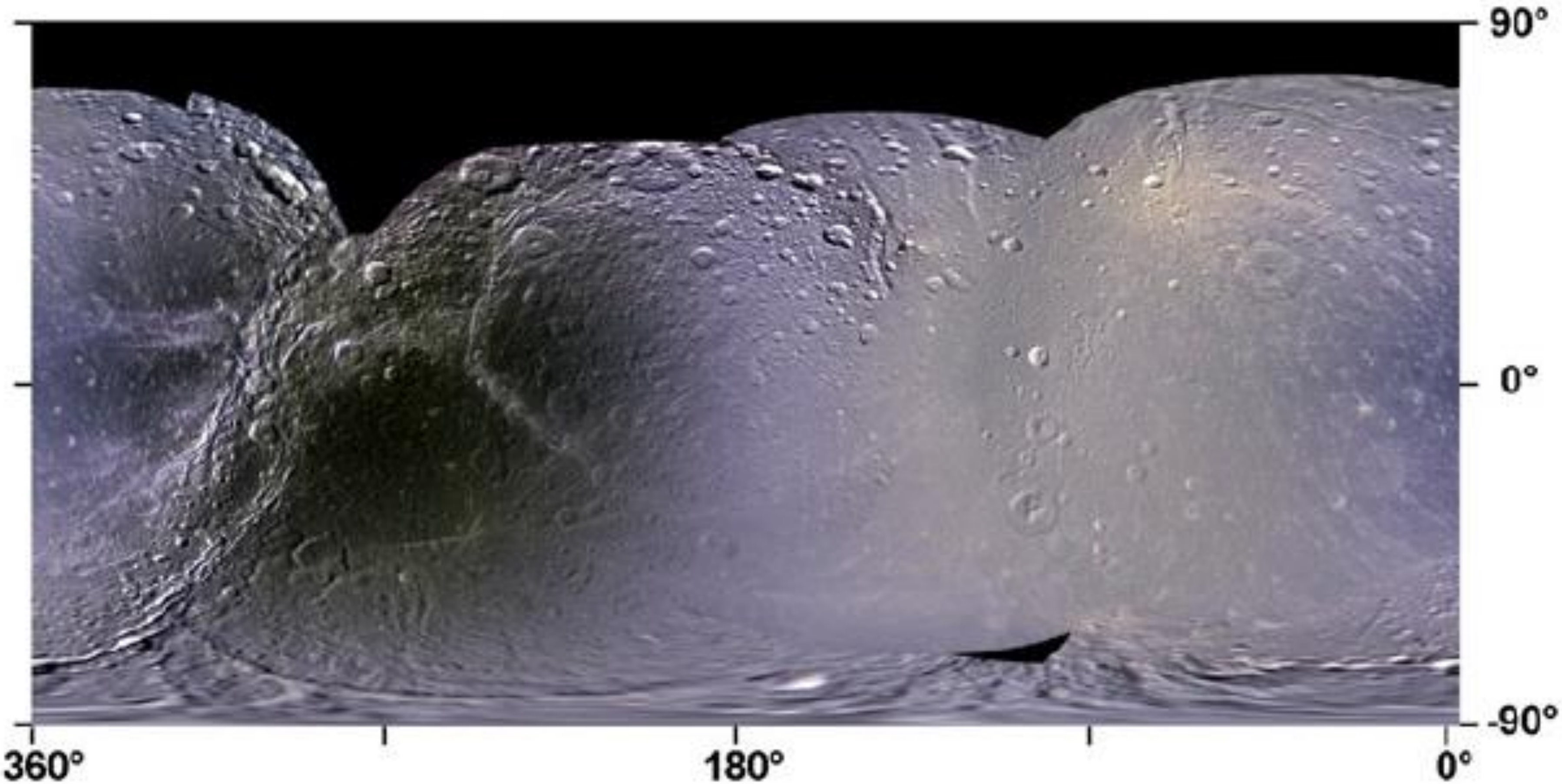


Dose in water and radiation transported in water

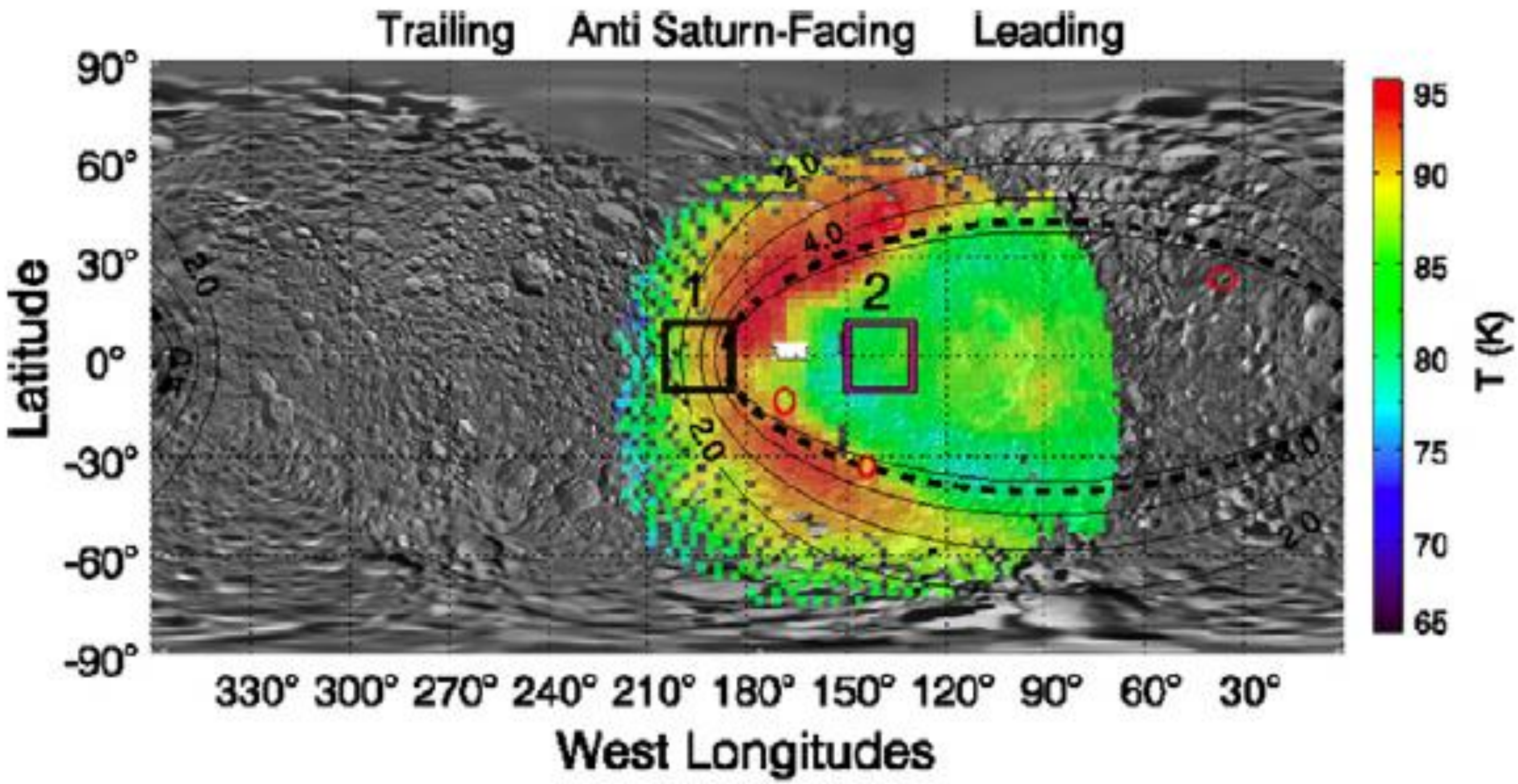
Fig. 10. After *Cooper and Sturner* (2006). Dose rate vs. depth where 1 rad/s is equal to 100 erg/gm/s or about 0.06 eV/H_2O-molecule/yr. The curve labeled "trailing hemisphere" includes the dose rate of 1–20-MeV electrons only, whereas the curve below it labeled leading hemisphere displays the dose rate of 20–40-MeV electrons that drift opposite to corotation. The uppermost of all the curves is the dose rate corresponding to electrons from 10 keV to 100 MeV and the dose rate from protons between 10 keV and 100 MeV follows this curve below it. Spikes and fluctations in the computed curves arise from statistics of limited number of Monte Carlo events used in the simulations and not from physical processes. Times in years are shown to give chemically significant (most bonds are broken at least once) dose of 100-eV/16-amu (60 Gigarads) at selected dose levels.

Paranicase, et al., in Europa
University of Arizona Press, 2009

Plasma "bull's eye" centered at 270°W on Dione seen as darkened area in this color ratio from Cassini ISS (Schenk et al. 2011)



MeV electron lens contours and thermal inertia anomaly on Mimas (Howett et al. 2011)



(a) Orbit 126

Cassidy et al. (2013) described a range of weathering patterns on Europa using sulfur ions of different energies. The sulfur is most abundant at low energy.